negatively charged chemical atom is one having a surplus of electrons, the number depending on the valency, whilst a positively charged atom is one having a deficiency of electrons. Differences of electrical charge may thus be likened to debits and credits in one's banking account, the electrons acting as current coin of the realm.

"Radio-activity and the Electron Theory." By Sir WILLIAM CROOKES, F.R.S. Received February 4,—Read February 6, 1902.

Electrons emanating from radio-active bodies behave like material particles, and are impeded by the molecules of the surrounding medium, in contrast with ether waves, which are not thus affected except by absorption. It is not difficult to put these indications to test. A pair of shallow cells, A B (fig. 1), 1·5 mm. deep and 25 mm. square, were made by cementing slips of glass to a thick glass plate.

determines the equivalent number, *because* it determines the combining force. Or if we adopt the atomic theory or phraseology, then the atoms of bodies which are equivalents to each other in their ordinary chemical action have equal quantities of electricity naturally associated with them."—*Ibid.*, par. 869.

"In former investigations of the action of electricity it was shown . . . that the quantity of electric power transferred onwards was in proportion to, and was definite for, a given quantity of matter moving as anion or cation onwards in the electrolytic line of action; and there was strong reason to believe that each of the particles of matter then dealt with, had associated with it a definite amount of electrical force, constituting its force of chemical affinity."—*Ibid.*, par. 1707.

(In all the above quotations the italics and capitals are Faraday's.)

"It is therefore extremely natural to suppose that . . . every molecule of the cation is charged with a certain fixed quantity of positive electricity, which is the same for the molecules of all cations, and that every molecule of the anion is charged with an equal quantity of negative electricity."—Clerk Maxwell's 'Treatise on Electricity and Magnetism,' First Edition, vol. 1, 1873, p. 308.

"This definite quantity of electricity we shall call the molecular charge. If it were known, it would be the most natural unit of electricity."—*Ibid.*, p. 311.

"Suppose . . . we call this constant molecular charge, for convenience in description, *one molecule of electricity*."—*Ibid.*, p. 312. (The italics are Maxwell's.)

"Nature presents us with a single definite quantity of electricity . . . For each chemical bond which is ruptured within an electrolyte a certain quantity of electricity traverses the electrolyte, which is the same in all cases."—G. Johnstone Stoney, "On the Physical Units of Nature," British Association Meeting, 1874, Section A, 'Phil. Mag.,' May, 1881.

"The same definite quantity of either positive or negative electricity moves always with each univalent ion, or with every unit of affinity of a multivalent ion."—Helmholtz, Faraday Lecture, 1881.

"Every monad atom has associated with it a certain definite quantity of electricity; every dyad has twice this quantity associated with it; every triad three times as much, and so on."—O. Lodge, "On Electrolysis," 'British Association Report,' 1885.

The cells were filled to the same depth with a radio-active substance chiefly containing actinium.* Over cell A was placed a piece of thick lead pipe, 28 mm. high and 25 mm. internal diameter, to insure that any emanations from the active substance in A would be confined to the inside of the hollow cylinder. The radio-active substance in B

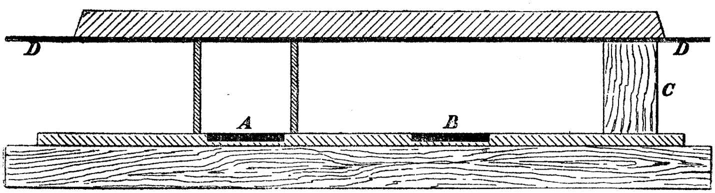

FIG. 1.—Elevation.

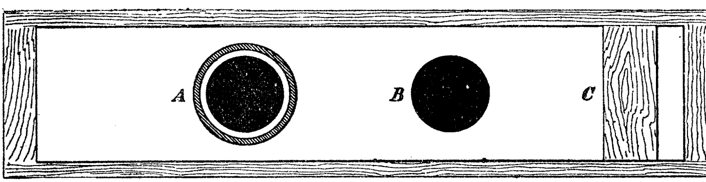

FIG. 1.—Plan.

was freely exposed to the air, save for a pillar of lead at C, to support the sensitive film. A sensitive film was laid horizontally over the cylinder and support C. On the film was a plate of glass, and cylinder and film were pressed together by heavy weights. The whole was covered in a light-tight box and put in a dark cupboard.

At the end of 48 hours the film was removed and developed. There was a strong action shown over cell A (the one covered by the lead cylinder), but over B, the cell exposed to the air, there was no visible impression. Measured in Mr. Chapman Jones's "Opacity Meter" † the results were :—

Image over cylinder—opacity log.‡ = 0·79; opacity§ = 6·17.

The experiment was repeated, using the same apparatus but a different preparation of actinium. In this case the exposure was for

* The body I called Uranium X in my Royal Society paper, May 10, 1900, has since proved to be M. Debierne's Actinium.

† 'The Photographic Journal,' vol. 20, p. 86, December 21, 1895.

‡ The opacity logarithm represents the density of the image, absolute density being represented by 2·00

§ The "opacity" is the whole number corresponding to the "opacity log." The "opacity" is directly proportional to the photographic energy acting on the sensitive surface.

72 hours. As before, there was a strong impression over cell A and none over cell B. The figures were :—

Opacity log. = 0·89 ; Opacity = 7·71.

These experiments indicate that the electrons from the radio-active agent, chiefly actinium, partake of the properties of a fog or mist of material particles, capable of diffusing away in the free air like odoriferous particles, when not kept in by a thick metal screen.

A further experiment was now tried with the same apparatus, the agent a strongly active radium and barium bromide. This material being self-luminous, a sheet of black paper was placed immediately over it, so that nothing but emanations capable of passing through the opaque paper would be subject to experiment. After 4 hours' exposure in total darkness, the film was developed. A good circular patch was obtained over cell A, and a faint diffused darkening showed over the rest of the film, darker at the spot immediately over cell B, fading away at the sides as the distance became greater. That this action was due to the material in the open cell B, and not to general fog over the plate, was seen by the clearness of the film where covered by the lead, and where shadows were thrown by the lead cylinder and pillar.

Circles of the same diameter were drawn round the dark impression over A, and round the darkest part of the impression over cell B. Measurements were taken of different parts of the spaces enclosed in these circles, and the mean of all these came out—

Circle over cell A—Opacity log. = 0·53 ; Opacity = 3·39.
Circle over cell B—Opacity log. = 0·32 ; Opacity = 2·09.

Ratio B/A = 0·62

The experiment was repeated with the addition of a sheet of aluminium, 0·02 mm. thick, under the black paper, the electrons now having to pass through both paper and metal before reaching the film. The exposure was for 6 hours, and the appearance on development was very similar to the last: a dark disc over the protected cell A, and a diffused action over the other part of the film, except in the shadow of the lead supports. Measurements as on the previous occasion gave the following results :—

Circle over cell A—Opacity log. = 0·78 ; Opacity = 6·03.
Circle over cell B—Opacity log. = 0·48 ; Opacity = 3·02.

Ratio B/A = 0·5.

A third experiment was tried with the same apparatus, using only the aluminium plate as a screen to cut off the luminous rays. The appearance on development was similar to the others, and the measurements of opacities were—

Circle over cell A—Opacity log. = 0·59; Opacity = 3·89.
Circle over cell B—Opacity log. = 0·29; Opacity = 1·95.

Ratio B/A = 0·5.

Finally, I tried polonium subnitrate, which gives off emanations hardly capable of passing through any screen, and greatly obstructed by a few centimetres of air.

The apparatus was substantially the same as the one just described, with the modification that the lead cylinder was 12 mm. high, and at the other end a rod of glass 12 mm. high was used to support the film. The reduced height was chosen, experience showing that polonium emanations have great difficulty in penetrating many millimetres through air. The exposure was 7 days, at the end of which time the film was developed. Over cell A a dark disc sharply defined the inside of the cylinder, while over cell B was a hazy diffused patch which to the eye looked much the fainter of the two. But measurements of patch A and of a disc over cell B of the same size as A, showed that the opacities in each case were practically identical, as shown by the following figures—

Circle over cell A—Opacity log. = 0·74; Opacity = 5·49.
Circle over cell B—Opacity log. = 0·76: Opacity = 5·75.

Ratio B/A = 1·05.

A repetition of the experiment, taking the mean of five concordant results, gave the same opacities as before.

Without proving that the emanations from polonium are less material than those from actinium and radium, this experiment shows that their behaviour is entirely different as regards diffusibility through air. Whether this is due to the larger mass of the individual particles, or to the less distance they have to travel (12 mm. as against 28 mm. in the case of actinium and radium), or to some other cause, further experiments must decide.

M. and Mdme. Curie have shown that radio-activity is communicable from radium and actinium compounds to bodies such as lead, copper, glass, ebonite, and paraffin. After exposure to emanations from the radium compound, these bodies have the property of communicating temporary conductivity to the air and other gases, and of thereby discharging an electrified body.

When such charged bodies are exposed to the air, in a single day they lose the greater part of their activity. These phenomena are observed with different radio-active salts of radium, also with salts containing actinium; but polonium compounds, even when very active, do not communicate the effect.

Dr. Rutherford shows that air which has remained for some time in the neighbourhood of thoria and then is carried in a current to a

distance, retains its property of communicating radio-activity to other bodies. He explains these phenomena by supposing that thoria gives off a special kind of emanation capable of being conveyed by the air, and that this is the cause of the induced radio-activity.

To ascertain if the electrons or corpuscles from radium also possess the property of being carried along in a current of air, I fitted up an apparatus shown in fig. 2. A, B, and C are three brass tubes closed

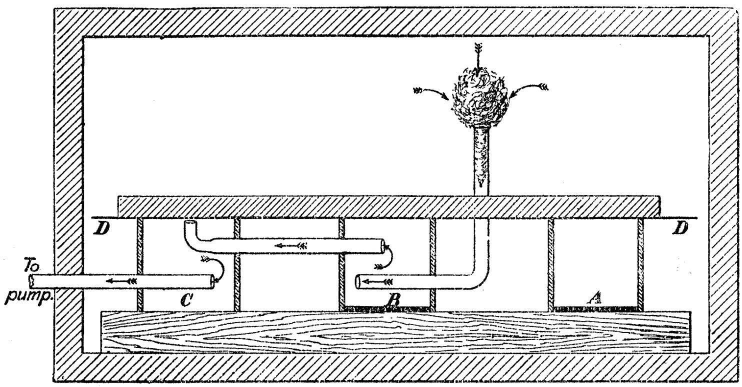

FIG. 2.—Elevation.

at the lower end and cemented with paraffin to a wooden block. The upper ends were accurately ground to a level surface, and then coated with a thin layer of paraffin wax. Holes were drilled in B and C, to admit glass tubes, cemented air-tight into the cylinders, as shown in the figure. The upper end of the tube in B was closed with a plug of cotton wool, and the outer end in C was connected to a water-pump, so that when the cylinders were closed at the top a current of air was drawn through B and C. As the radium compound was self-luminous, discs of thin aluminium foil were placed over cylinders A and B to cut off the luminous rays. A sensitive film was laid on the three cylinders over the aluminium, and it was tightly pressed down by a heavy weight; the contact between the film and the tops of the cylinders being sufficient to make the whole air-tight. At the bottom of A and B a radium compound was placed, equal weights and equal surface in each. The whole was put into a light-tight box, and air drawn through. The cylinder A was used only as a standard. The air passing into B was expected to carry along with it some of the corpuscles emitted from the active material at the bottom; and the inlet tube in C was turned up at the end, so that the stream of corpuscles-laden air should impinge on the surface of the centre of the film on C, and if it carried with it any radio-active properties the result should be seen on development,

by the production of a dark patch. If, however, the air carried no corpuscles there would be no image on the sensitive film over C.

The experiment was continued for 11 hours, 120 litres of air having passed through in the time.

On development and measuring the resulting images the following figures were obtained:—

Circle over cell A—Opacity log. = 0·342; Opacity = 2·20.
Circle over cell B—Opacity log. = 0·178; Opacity = 1·51.
Circle over cell C—Opacity log. = 0·025; Opacity = 0·11.

Ratio B/A = 0·68.

The apparatus was slightly altered. Cells B and C were put nearer together, and a short wide brass tube replaced the turned up glass tube formerly connecting them. The experiment was continued for 48 hours, during which time about 500 litres of air passed through the apparatus.

This repetition, allowing longer time, gave measurements as follows:—

Circle over cell A—Opacity log. = 0·964; Opacity = 9·20.
Circle over cell B—Opacity log. = 0·730; Opacity = 5·37.

Ratio B/A = 0·58.

In this experiment a slight but measurable darkening took place over cell C, shown by an opacity log. of 0·025 and an opacity of 0·11. This shows that some few corpuscles have been able to pass through the wide tube from B to C, and act on the photographic film.

It thus appears that a current of air passed over the surface of a radium compound carries with it a certain proportion of the corpuscles. This is proved by the diminished photographic action in the second cell, slightly confirmed by the evidence that some few of the corpuscles so carried away get to the sensitive film on cell C. Judging from our slender knowledge of the properties of free electrons, it is highly probable that they will not easily turn a corner, but cling to the sides of the tube through which they are being led. On the other hand, the constant collisions with the atoms of air may reduce their initial mobility almost to a vanishing point before they have travelled along the tube between B and C, and then they would be carried along with the air.

The experiment was repeated, using a preparation of actinium (Uranium X). It was kept going for 72 hours, during which time 750 litres of air were drawn through the apparatus. On development and measurement the following results were obtained:—

Circle over cell A—Opacity log. = 0·99; Opacity = 9·78.
Circle over cell B—Opacity log. = 0·67; Opacity = 4·68.
Circle over cell C—Opacity log. = 0·25; Opacity = 1·78.

Thoria prepared by the ignition of Dr. Knöfler's highly purified thorium nitrate* was now tested in a similar apparatus to the one last described, the only alteration being the removal of the covering aluminium plates, thoria not being self-luminous. The experiment was continued for 108 hours, 1125 litres of air being drawn through the cells during the time.

Measurements of the developed images gave the following results:—

Circle over cell A—Opacity log. = 0·306; Opacity = 2·02.
Circle over cell B—Opacity log. = 0·260; Opacity = 1·82.
Circle over cell C—Opacity log. = 0·046; Opacity = 0·10.

Here also the results agree with those tried with radium and actinium compounds, that corpuscles are carried by a current of air from cell B, through the connecting tube to cell C. They also confirm those of Dr. Rutherford—who finds that thorium emanations travel in a current of air while retaining their activity—and of P. Curie and A. Debierne, who show that induced radio-activity can be transmitted through capillary tubes of an internal diameter of 0·1 mm. and 75 cm. in length, bent once at right angles.

I have not obtained, however, a similar result with the emanations from hydrogen peroxide. As shown by Dr. Russell, this substance has a strong action on a sensitive photographic plate. The emanation from a bottle half full of hydrogen peroxide acts strongly on a sensitive film laid over the open mouth of the bottle for 24 hours, while there is no action in 72 hours if a U-shaped tube passed through the cork of the bottle and the sensitive film is put close to the open end of the tube. Dr. Russell tells me his observations confirm my experiments.

A highly active self-luminous radium compound loses some of its power on long exposure to the ordinary air of the laboratory. Ignition to red-heat restores, however, its self-luminosity, and when sealed in a vacuum its activity remains as great as at first. When enclosed in glass the glass soon assumes a pink colour, which is not superficial, as already observed by M. and Mdme. Curie. By immersing a section of the glass in a liquid of the same refracting power as itself, the colour is seen to penetrate below the surface. If, however, the radium compound is sealed *in vacuo* in a *quartz* tube no coloration takes place, and I can detect no diminution of energy even in 12 months.

Electrons from radium will pass through aluminium and a considerable length of air and affect a sensitive film.† Experiments on this point were tried with polonium, and it was found that air offered great obstruction.

* 'Roy. Soc. Proc.,' vol. 66, p. 421, May, 1900.

† Using an active compound of radium, I have obtained an impression on a sensitive film through a penny-piece.

Three shallow cells 17 mm. in diameter and 2 mm. deep were filled with polonium subnitrate, the same quantity in each cell, the surfaces being levelled. Over these cells were fixed three pieces of lead pipe of lengths of 1, 2, and 4 inches, so that each cell of polonium had its emanations confined to its own tube. Sensitive films were put over each tube, and the whole kept in total darkness for 144 hours. At the end of that stretch of time the films were developed. No image was seen on the film 4 inches from the polonium, a faint image was perceptible on the film 2 inches off, and a stronger one on the film 1 inch off. Measured in the opacity meter the figures were:—

Over 1 inch tube—Opacity log. = 0·18; Opacity = 1·51.
Over 2 inch tube—Opacity log. = 0·04; Opacity = 0·11.

A repetition of this experiment, using tubes of glass instead of lead, gave almost identical results.

The electron theory explains a fact which has long puzzled experimentalists. It is well known that if a coin is laid on a sensitive plate in perfect darkness and connected with one pole of an induction coil for a few seconds and then developed, an image can be obtained of the raised parts of the coin. This has generally been explained by saying that the electrified stream of air, or the "brush discharge," affects the film like light.

But Mr. F. Sanford* shows that coins embedded in the centre of a block of paraffin 2 cm. thick, where they could not send off streams of electrified air, can still be photographed by means of the induction coil. Under these circumstances it is probable that electrons are the agents, as electrons will easily pass through paraffin wax from the coin to the sensitive plate, when the coin is connected with the negative pole of an induction coil, the other pole being connected with a metal plate placed below the wax block.

Hitherto we have been dealing with negative electrons—a free positive electron at present is unknown. In a paper communicated to the Royal Society, December, 1900,† the Hon. R. J. Strutt offers a suggestion as to positive ions which in a satisfactory manner appears to explain much that hitherto has been left doubtful, not to say contradictory.

He adopts the generally recognised theory that the deflectable Becquerel rays consist of a stream of negative corpuscles with enormous velocities proceeding from the radio-active body. But there are two kinds of Becquerel rays, one deflectable and penetrating, the other non-deflectable and easily absorbable. Mr. Strutt considers that these non-deflectable rays are positive ions moving in a stream from the radio-active body.

* 'Nature,' vol. 55, p. 485.

† 'Phil. Trans.,' A, 1901, vol. 196, p. 525.

He says:—"We know that the positive ions in gases carry the same charge as the negative, and that they have an enormously greater mass. Unless, therefore, their velocity is smaller out of all proportion than the negative ions, it is to be expected that they will be much less easily deflected by the magnet. . . . Next it may be noticed that the smaller penetrating power would be well accounted for by the size of the positive ions, which would, of course, make more collisions with the molecules of the surrounding gas than the much smaller negative ions."

Of the three radio-active bodies, radium, actinium, and polonium, actinium appears to emit corpuscles almost entirely of the penetrating, deflectable kind, polonium rays of the non-deflectable, non-penetrating kind, whilst radium emits rays of both kinds.

On the above hypothesis corpuscles from polonium might consist of the heavy positive ions: to test the accuracy of this inference experiments are now in progress.

Some curious and far-reaching inferences may be drawn from Mr. Strutt's view, supposing it to be correct, that positive as well as negative corpuscles will fly off from a radio-active body. In a paper "On Electrical Evaporation"* I showed that many bodies, such as silver, gold, platinum, &c., usually considered non-volatile at ordinary temperatures, easily volatilise in a vacuum if connected with the negative pole of an induction coil, remaining fixed when connected with the positive pole. This phenomenon was first observed by Dr. Wright, of Yale College, and was applied by him for the production of mirrors for physical apparatus. It is shown by experiments that the action in the vacuum tube is of two kinds. A silver pole was used, and near it, in front, was a sheet of mica with a hole in its centre. The vacuum was very high (P = 0·00068 mm.), and when the poles were connected with the coil, the silver being negative, electrons shot from it in all directions, and passing through the hole in the mica screen, formed a bright phosphorescent patch on the opposite side of the bulb. The action of the coil was continued for some hours, to volatilise a certain portion of the silver. On subsequent examination it was found that silver had been deposited only on the mica screen and in the immediate neighbourhood of the pole; the far end of the bulb, at the spot which had been glowing for hours from the impact of electrons, being free from silver deposit. Here then are two simultaneous actions. Electrons, or as I once called them "Radiant Matter," shot from the negative pole, and caused the glass against which they struck to glow with phosphorescent light. Simultaneously the heavy positive ions of silver, freed from their negative electrons, or under the

* 'Roy. Soc. Proc.,' vol. 50, p. 88, June, 1891.

influence of the electrical stress, likewise flew off, and were deposited in the metallic state near the pole.

An experiment was tried to discover if the ions of metal, deposited in this manner on a metal plate connected with an idle pole, in the full stream of + ions and − electrons, showed any special + or − electrification. In all cases the electrification was positive. This lends support to Mr. Strutt's view that + ions as well as − electrons will fly off from a radio-active body. Even these results, however, must not be taken as conclusive, for in a paper published in 1891,* I showed that at a high vacuum nearly the whole of the interior of a tube through which an induction spark was passing was electrified positively, negative electrification being detected only in the immediate neighbourhood of the negative pole.

During the course of my experiments a curious circumstance was observed, which deserves record as it may elucidate some of these obscure phenomena. While the volatilisation of the silver pole is rapidly proceeding, the metal glows as if red-hot. This "red heat" is superficial only. The metal instantly assumes, or loses, the appearance of red heat the moment the current is turned on or off, showing that the high temperature does not penetrate below the surface. The volatilisation of the positive ions is confined to the surface, and the surface glow is connected with that action. If instead of silver, a good conductor of heat, I take diamond, a bad conductor, the surface layers are changed sufficiently to convert them into a form of graphite, which from its great resistance to oxidising agents, cannot be formed at a lower temperature than 3600° C.

"The Density and Coefficient of Cubical Expansion of Ice." By J. H. VINCENT, D.Sc., B.A., St. John's College, Cambridge. Communicated by Professor J. J. THOMSON, F.R.S. Received January 22,—Read February 6, 1902.

(Abstract.)

After an account of the methods employed by previous experimenters in the subject, reference is made to the views of Nichols, according to which two distinct kinds of ice have been subjected to experiments. The density of artificial ice is about 0·916 gramme per cubic centimetre, while that of natural ice is more than one part in a thousand greater.

* "Electricity in Transitu: from Plenum to Vacuum," 'Journ. Inst. Elect. Engin.,' vol. 20, p. 10.

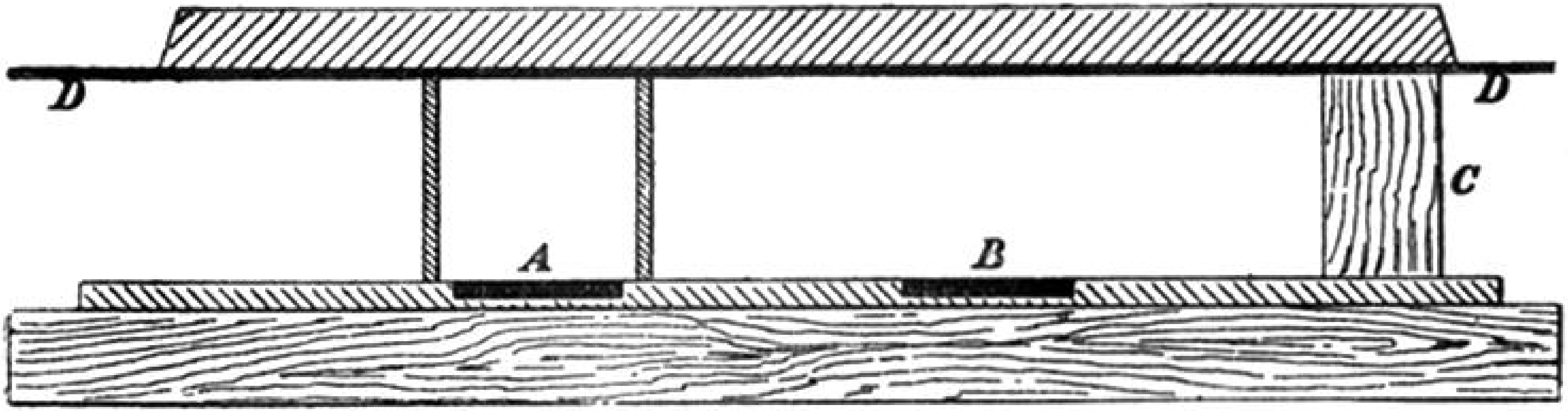

FIG. 1.—Elevation.

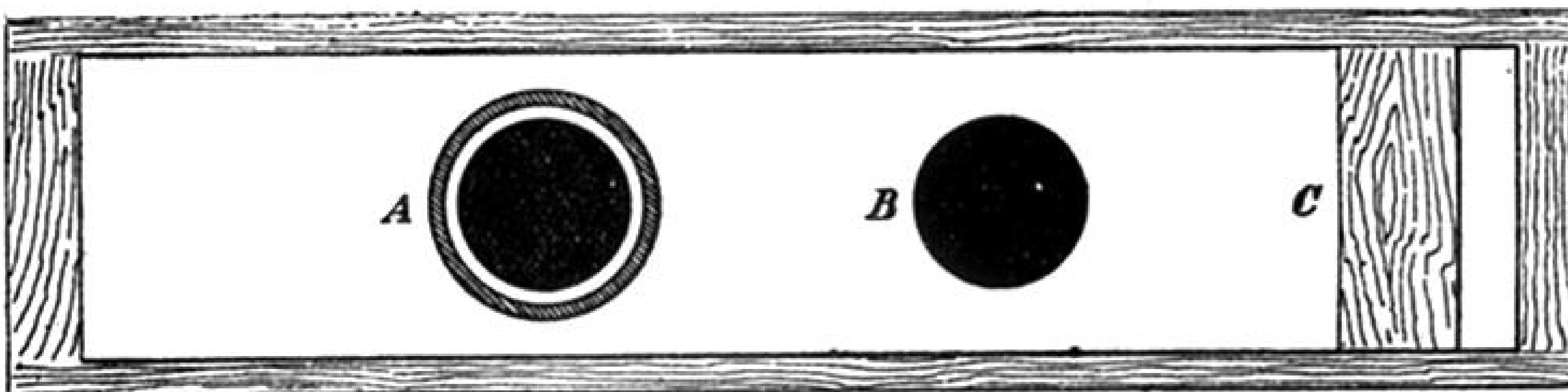

FIG. 1.—Plan.

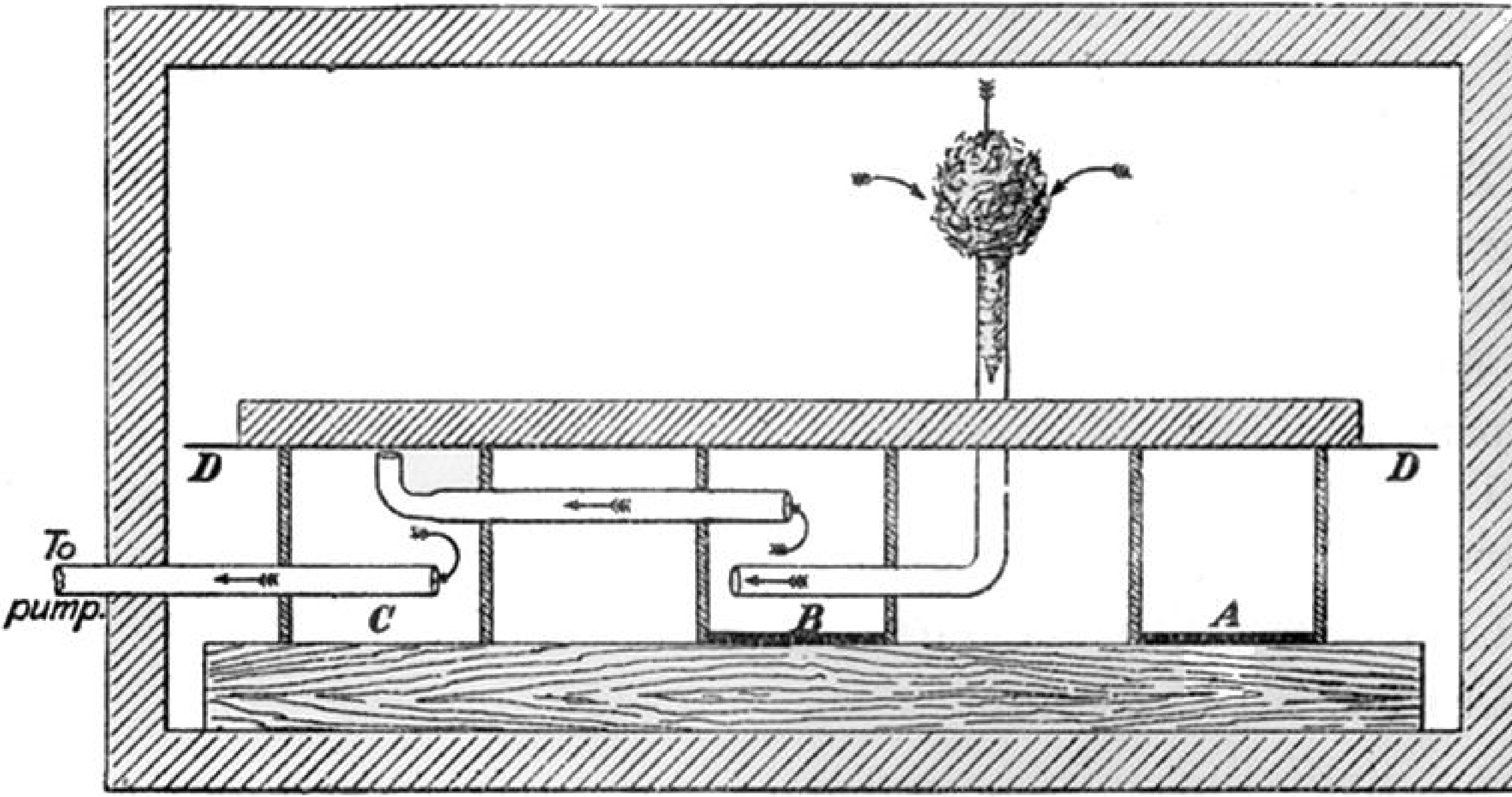

FIG. 2.—Elevation.